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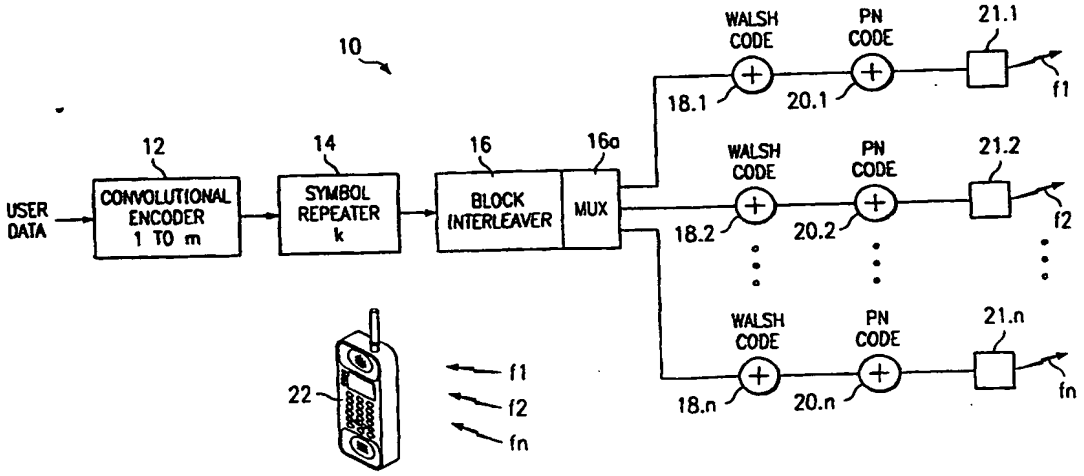

(57) Abstract

A system and method that codes and interleaves data onto separate channels for transmission in a wireless multicarrier system, further comprising a code division multiple access (CDMA) transmitter for each of the carriers. The multicarrier wireless transmission system has an input terminal for receiving a plurality of user data bits. The system adds error–correcting bits to the user data bits. The system then arranges and stores the combination of error–correcting bits, collectively coded symbols, in a two dimensional matrix. The system arranges the coded symbols by writing them into the matrix according to columns, from left to right. The system then retrieves the symbols from the matrix according to rows, from top to bottom. The system then transmits the retrieved symbols on different carrier frequencies such that consecutive symbols are each transmitted on a different carrier frequency.

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CHANNEL CODING AND INTERLEAVING FOR TRANSMISSIONS ON A MULTICARRIER SYSTEM

Technical Field

The invention relates generally to transmitting and receiving data in a telecommunication system and, more particularly, to a system and method for coding and interleaving data onto separate channels for transmission in a multicarrier system.

Background of the Invention

Generally, a wireless telecommunication system serves a defined area by dividing the area into cells. Each cell is served by a single base station, or cell site, and each cell site is connected to a message switching center ("MSC") via appropriate hardware links. A mobile unit is connected to the MSC by establishing a link with a nearby cell site using one or more radio frequency ("RF") channels, or carriers.

For various reasons, higher data rates are desirable in the RF link between the mobile unit and the cell site. For example, in a code division multiple access ("CDMA") system, data rates are somewhat restricted due to current standards that require a system bandwidth of 1.25 Megahertz (MHz). However, future requirements are expanding to support a system bandwidth of $n \times 1.25$ MHz, where n is an integer, thereby supporting backwards compatibility to the traditional 1.25 MHz bandwidth.

Once a system bandwidth of $n \times 1.25$ MHz is chosen, there are two conventional methods by which the data may be transmitted over the chosen bandwidth. One method, referred to as direct spread, encodes the data using a convolutional code, interleaves the resulting coded bit stream, encodes the interleaved symbols using a Walsh code unique to the user, further encodes the encoded symbols using a pseudo-noise (PN) code, and then transmits the resulting symbols, known as chips, on the entire $n \times$

1.25 MHz bandwidth. Using this method, the actual symbol rate on the RF carrier is $n \times 1.25$ million chips per second. Another method, referred to as multicarrier, splits the encoded data into n streams, encodes each stream using a Walsh and a PN code, and then transmits the resulting chips of each stream on a separate 1.25 MHz carrier. A CDMA compatibility standard for cellular mobile telecommunications systems, including greater detail in the above described methods, is described in MOBILE STATION-BASE STATION COMPATIBILITY STANDARD FOR DUAL-MODE WIDEBAND SPREAD SPECTRUM CELLULAR SYSTEM, TIA/EIA/IS-95 (July 1993), which is hereby incorporated by reference.

The multicarrier method described above does not adequately handle error conditions that occur over the separate carriers. For example, if several bit errors occur in sequential order, even the existence of error correcting code in the bit stream does not prevent certain data bits from being lost. To alleviate this problem, the multicarrier method interleaves, or shuffles, the order of the data bits separately on each carrier before transmission and then de-interleaves the data bits at the receiving end. This solution, however, has several deficiencies. For one, shuffling circuits are often used for each carrier, thereby requiring extra circuitry. Also, the shuffling does not take into account that certain carrier frequencies may be more robust at any particular time, and therefore subject to less errors than the other carrier frequencies.

Therefore, what is needed is a system and method that codes and interleaves data onto separate carriers for transmission in a multicarrier system.

Furthermore, what is needed is a system and method that does not require individual interleaving circuitry for each carrier of the multicarrier system.

Furthermore, what is needed is a system and method that utilizes a different carrier for consecutive bits of the error correcting code, thereby providing a versatile system that is less prone to errors.

Summary of the Invention

The foregoing problems are solved and a technical advance is achieved by a system and method that codes and interleaves data onto separate channels for transmission in a telecommunication system. In one embodiment, the multicarrier telecommunication system has an input terminal for receiving a plurality of user data bits. The system may add error-correcting bits to the user data bits. The system then arranges and stores the combination of error-correcting bits, collectively coded symbols, in a two dimensional matrix. The system arranges the symbols by writing them into the matrix according to columns, from left to right. The system then retrieves the symbols from the matrix according to rows, from top to bottom and transmits the retrieved symbols on different carrier frequencies such that consecutive symbols are each transmitted on a different carrier frequency.

As a result, the system reduces the effect of errors resulting from any single carrier. Furthermore, the arranging of the symbols is performed at a central location, thereby obviating a need for each carrier to have its own shuffling device.

Brief Description of the Drawing

Fig. 1 is a block diagram of a base station and mobile unit in a multicarrier CDMA system.

Fig. 2 is a flow chart for a routine used to store symbols received by the base station of Fig. 1 into a matrix.

Fig. 3 is a flow chart for a routine to retrieve the symbols stored in the matrix of Fig. 2 for transmission.

Description of the Preferred Embodiment

Referring to Fig. 1, the reference numeral 10 designates a simplified base station of a multicarrier CDMA system. The base station 10 includes a convolutional encoder 12 (with a rate $1/m$), a symbol repeater (k times) 14, and a block interleaver 16 having an inverse-multiplexer 16a. The base station 10 utilizes multiple (n) carriers on separate frequencies *f1* - *fn*, each with a bandwidth of 1.25 MHz and each adding a conventional Walsh code 18.1 - 18.n and PN code 20.1 - 20.n before being processed (baseband filtering, upconversion, amplification) and transmitted by devices 21.1 - 21.n, respectively. For the sake of example, only the forward link from base station 10 to a mobile unit 22 will be discussed, where a frame of r user data bits is received by the base station and a symbol stream divided of $m \times k \times r$ size blocks is transmitted.

When each bit of the user data enters the convolutional encoder 12, it is encoded into m symbols. The encoded symbols are then provided to the symbol repeater 14 where each symbol is repeated k times. The convolutional encoder 12 and the symbol repeater 14 are conventional devices for providing error-correcting capability, and for the sake of brevity, will not be further discussed.

Referring to Fig. 2, a method 50 is used to interleave the symbol stream produced from the symbol repetition block 14. At step 52, the block interleaver 16 forms a matrix of $m \times k \times q$ rows by p columns, where q and p are positive integers and

$$p \times q = r. \tag{1}$$

At step 54, the block interleaver 16 writes the encoded symbols into the matrix starting at the top of the first column and continuing down to the bottom of the first column. Once the first column is written, the symbols are filled into the second column from top to bottom. Step 54 is continued until all columns of the matrix are filled.

Referring to Fig. 3, once the matrix has been filled, a routine 70 is used to retrieve the symbols from the matrix for transmission on the different carriers *f1* - *fn*. At step 72, the inverse-multiplexer 16a retrieves the first symbol on the first row and at step 74, sends the first symbol to the device 21.1 to be transmitted on carrier *f1*. At step 76, the inverse-multiplexer then sends the following symbols on the first row sequentially to be transmitted on carriers *f2* through *fn*, one on each carrier until a symbol is transmitted on each of the *n* carriers. This step is then repeated with the next *n* symbols on the first row until all symbols of the first row are transmitted. At step 78, a determination is made as to whether any more rows are available. If not, execution stops. Otherwise, execution returns to step 72 where the inverse-multiplexer 16a retrieves the first symbol of the second row and at step 74, sends this symbol to the device 21.2 to be transmitted on the carrier *f2*. The inverse-multiplexer then sends the following symbols on the second row to be transmitted on carriers *f3*, *f4*, ..., *f1* until *n* symbols are transmitted on each of the *n* carriers. This step is then repeated with the next *n* symbols on the second row until all symbols of the second row are transmitted. If more rows remain, the inverse-multiplexer 16a returns to step 72, retrieves the first symbol of the third row on carrier *f3*, and sends the remaining symbols to be transmitted on carriers *f4*, *f5*, ..., *f4*, and so forth. On row $n+1$, the inverse-multiplexer 16a sends the first symbol to be transmitted on carrier *f1*, and the steps 72-78 are repeated. Likewise, the transmission of rows $n+2$, $n+n+2$, $n+n+n+2$, *etc.*, each start with carrier *f2*, and so forth for the remaining rows.

For the sake of example, a frame of 10 user data bits ($r = 10$) is encoded using a 1-to-3 ($m = 3$) rate convolutional code, repeated twice ($k = 2$) and then divided between three different carrier signals ($n = 3$). The resulting symbol stream is divided into blocks of 60 symbols, which are interleaved across time as well as the 3 carrier signals. A matrix, illustrated in Table 1, has twelve columns ($q = 2$) and five rows ($p = 5$).

Each symbol of the matrix is represented as either X_i, Y_i or Z_i which together represent the three bits that are generated from one information bit by the convolutional encoder 12, where i is between 1 and 10. Furthermore, each of the symbols X_i, Y_i and Z_i are repeated twice by the symbol repeater 14. Using the method 50 described above, the symbols are written into the columns of the matrix as illustrated below.

Table 1 Interleaving Matrix

X_1	Z_1	Z_2	Y_3	Y_4	X_5	X_6	Z_6	Z_7	Y_8	Y_9	X_{10}
X_1	X_2	Z_2	Z_3	Y_4	Y_5	X_6	X_7	Z_7	Z_8	Y_9	Y_{10}
Y_1	X_2	X_3	Z_3	Z_4	Y_5	Y_6	X_7	X_8	Z_8	Z_9	Y_{10}
Y_1	Y_2	X_3	X_4	Z_4	Z_5	Y_6	Y_7	X_8	X_9	Z_9	Z_{10}
Z_1	Y_2	Y_3	X_4	X_5	Z_5	Z_6	Y_7	Y_8	X_9	X_{10}	Z_{10}

Once the symbols have been arranged in the matrix, the inverse-multiplexer 16a retrieves the symbols in an interleaved manner for transmission on the carriers *f1*, *f2*, and *f3*. Moving across each row of the matrix of Table 1 in sequential order, the inverse-multiplexer sends each symbol to be transmitted in the following sequence, as described in Table 2, below. In Table 2, the column "No." describes the sequence that each symbol is transmitted, the column "Symbol" corresponds to the name from Table 1, the column "(R,C)" identifies the row and column of Table 1 in which the symbol is stored, and the column "Freq." designates the carrier on which the symbol is transmitted.

Table 2 Transmission Sequence

No.	Symbol	(R,C)	Freq.
1	X_1	1,1	*f1*
2	Z_1	1,2	*f2*
3	Z_2	1,3	*f3*
4	Y_3	1,4	*f1*
5	Y_4	1,5	*f2*
6	X_5	1,6	*f3*
7	X_6	1,7	*f1*
8	Z_6	1,8	*f2*
9	Z_7	1,9	*f3*
10	Y_8	1,10	*f1*
11	Y_9	1,11	*f2*
12	X_{10}	1,12	*f3*
13	X_1	2,1	*f2*
14	X_2	2,2	*f3*

No.	Symbol	(R,C)	Freq.
15	Z_2	2,3	*f1*
16	Z_3	2,4	*f2*
17	Y_4	2,5	*f3*
18	Y_5	2,6	*f1*
19	X_6	2,7	*f2*
20	X_7	2,8	*f3*
21	Z_7	2,9	*f1*
22	Z_8	2,10	*f2*
23	Y_9	2,11	*f3*
24	Y_{10}	2,12	*f1*
25	Y_1	3,1	*f3*
...	...	...	...
59	X_{10}	5,11	*f2*
60	Z_{10}	5,12	*f3*

It is understood that the mobile unit 22 has a similar broadcasting feature as described above for the base station 10. Furthermore, both the mobile unit 22 and the base station 10 also include receiver units for receiving and storing each symbol in a scheme opposite to the scheme described above, thereby allowing the data stream to be de-interleaved and fully restored.

In another embodiment, the block interleaver 16 may retrieve the symbol at the j^{th} column and i^{th} row of the matrix on carrier frequency f_m such that:

$$m = (((j-1)\times r + i - 1) \text{ MOD } n) + 1, \quad (2)$$

where r is the number of rows in the matrix, n is the number of carrier frequencies such that $1 \leq m \leq n$, and the function MOD signifies a modulus operation. By using equation (2) above, the interleaver 16 is ensured that no two consecutive coded symbols in the original coded sequence are transmitted on the same carrier frequency.

Therefore, although illustrative embodiments of the invention have been shown and described, other modifications, changes, and substitutions are intended in the foregoing disclosure. For example, the convolutional encoder 12 could be left out so that the symbol repeater 14 provides the only source of error correction capability. Also, Table 1 can be arranged according to rows, thereby allowing Table 2 to retrieve the symbols according to columns. Furthermore, the present invention is not limited to cell-based telecommunication systems, but instead may be used in many different types of systems, including wired-transmission systems. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

WHAT IS CLAIMED IS:

1. A telecommunication system comprising:

an input terminal for receiving a plurality of user data bits;

an error-correction device for generating a sequence of coded symbols from the user data bits;

an interleaver for arranging and storing the coded symbols in a matrix;

an inverse-multiplexer for retrieving the coded symbols stored in the matrix;

wherein the matrix is two-dimensional, the interleaver arranges the coded symbols according to the first dimension and the inverse-multiplexer retrieves the coded symbols according to the second dimension.

2. The system of claim 1 further comprising a device for repeating the coded symbols.

3. The system of claim 1 wherein the error correction device is a repeater and the sequence of coded symbols include duplicates of the user data bits.

4. The system of claim 1 being a wireless multicarrier system further comprising a code division multiple access ("CDMA") transmitter for each of the carriers.

5. The system of claim 4 wherein a sub-sequence of multiple coded symbols are generated for each user data bit and wherein consecutive symbols of the sub-sequence are transmitted on different carriers.

6. The system of claim 2 utilizing multiple carriers wherein the repeated coded symbols are sequentially transmitted on different carriers.

7. The system of claim 1 wherein the error-correction device provides forward error correction.

8. The system of claim 1 utilizing multiple carriers wherein each carrier operates at a common bandwidth.

9. The system of claim 1 utilizing only a single carrier.

10. The system of claim 1 including a plurality of carriers and wherein the system may selectively use one or more of the carriers.

11. A method for arranging a frame of consecutive bits for transmission in a multicarrier system, the method comprising the steps of:

arranging and storing each bit of the frame in a two-dimensional matrix according to the first dimension of the matrix;

retrieving each bit stored in the matrix according to the second dimension to form an interleaved sequence of bits;

transmitting the interleaved sequence of bits with multiple carriers such that no two consecutive bits in the interleaved sequence of bits are transmitted on the same carrier.

12. The method of claim 11 wherein the step of transmission utilized multiple carriers and no two consecutive bits of the frame are transmitted on the same carrier.

13. The method of claim 11 wherein the first dimension represents a plurality arrangements of the matrix, and where a first carrier transmits

the first bit of the first arrangement and the second carrier transmits the first bit of the second arrangement.

14. The method of claim 11 wherein the step of transmitting utilizes a code division multiple access ("CDMA") transmitter for each carrier of the multicarrier system.

15. The method of claim 11 wherein the frame of bits includes error-correcting code.

16. The method of claim 15 wherein the frame of bits also includes user data and the error-correcting code is a duplicate of the user data.

17. The method of claim 11 wherein each carrier of the multicarrier system operates at a common bandwidth.

18. The method of claim 11 wherein the multicarrier system utilizes only a single carrier.

19. A system for arranging a frame of consecutive bits for transmission in a multicarrier wireless system, the system comprising:

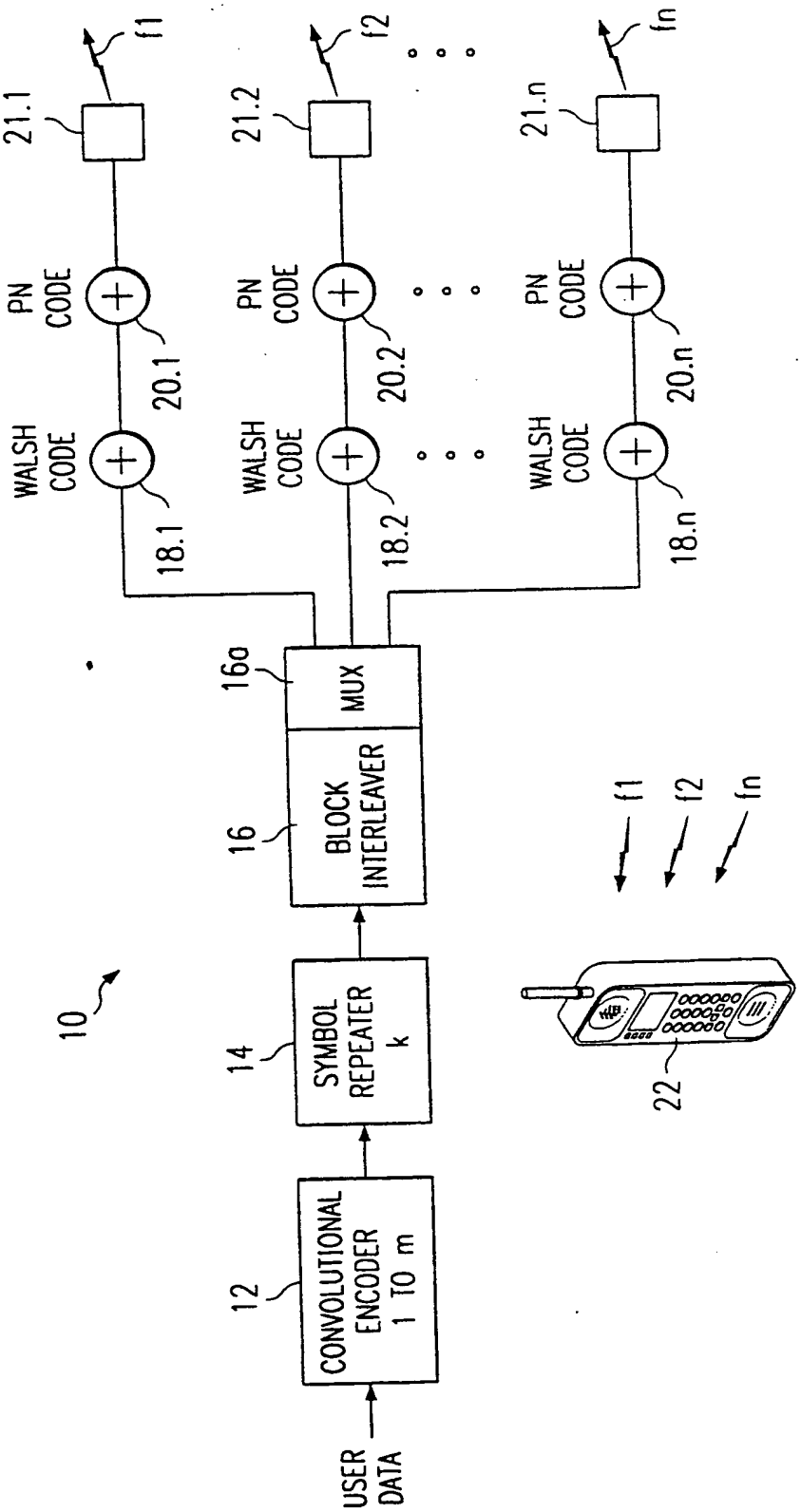
means for arranging and storing each bit of the frame in a two-dimensional matrix according to the first dimension of the matrix;

means for retrieving each bit stored in the matrix according to the second dimension to form an interleaved sequence of bits;

a code division multiple access transmitter for transmitting the interleaved sequence of bits wherein the step of transmission utilizes multiple carriers operating at a common bandwidth and wherein no two consecutive bits of the frame are transmitted on the same carrier.

wherein the first dimension represents a plurality arrangements of the matrix, and where a first carrier transmits the first bit of the first arrangement and the second carrier transmits the first bit of the second arrangement.

20. The system of claim 19 wherein the frame of bits includes error-correcting code.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CONVOLUTIONAL ENCODER 1 TO m
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SYMBOL REPEATER k
14
BLOCK INTERLEAVER
16
MUX
16a
10
WALSH CODE
18.1
18.2
18.n
PN CODE
20.1
20.2
20.n
21.1
21.2
21.n
f1
f2
fn
22

Fig. 1

Fig. 2

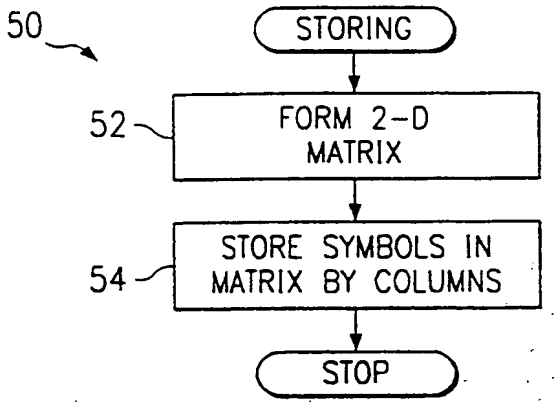
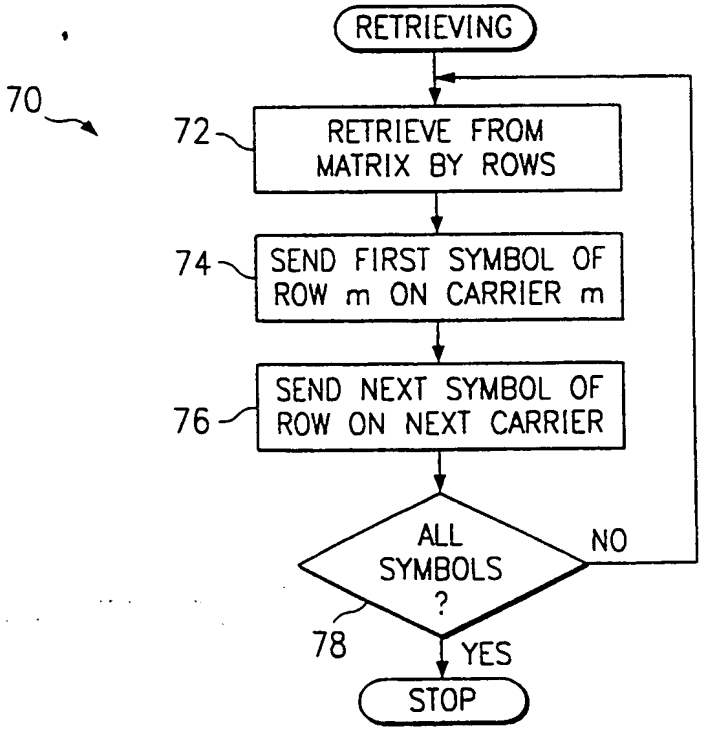

50
STORING
52
FORM 2-D MATRIX
54
STORE SYMBOLS IN MATRIX BY COLUMNS
STOP

Fig. 3


70
RETRIEVING
72
RETRIEVE FROM MATRIX BY ROWS
74
SEND FIRST SYMBOL OF ROW m ON CARRIER m
76
SEND NEXT SYMBOL OF ROW ON NEXT CARRIER
ALL SYMBOLS ?
NO
78
YES
STOP

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/CA 98/00594

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L27/26 H04L5/02 H04B1/69 H03M13/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04L H03M H04B H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 758 168 A (NIPPON TELEGRAPH & TELEPHONE) 12 February 1997 see column 1, line 5 - line 11 see column 6, line 6 - line 19 see column 17, line 56 - line 12; figure 3 see figures 9A,9B	1-3,7,9
Y		4-6,8, 11-20

X	WO 96 24196 A (PHILIPS ELECTRONICS NV ;PHILIPS NORDEN AB (SE)) 8 August 1996 see page 2, line 26 - page 3, line 15 see page 4, line 17 - page 5, line 27 see page 10, line 20 - page 12, line 22	1-3,7,9, 10
Y		4-6,8, 11-20

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
5 November 1998	18/11/1998

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/CA 98/00594

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHEN Q ET AL: "PERFORMANCE OF A CODED MULTI-CARRIER DS-CDMA SYSTEM IN MULTI-PATH FADING CHANNELS" WIRELESS PERSONAL COMMUNICATIONS, vol. 2, no. 1/02, 1 January 1995, pages 167-183, XP000589618 see page 168, paragraph 1 see figure 1	1-10
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A		5,11-20

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/CA 98/00594

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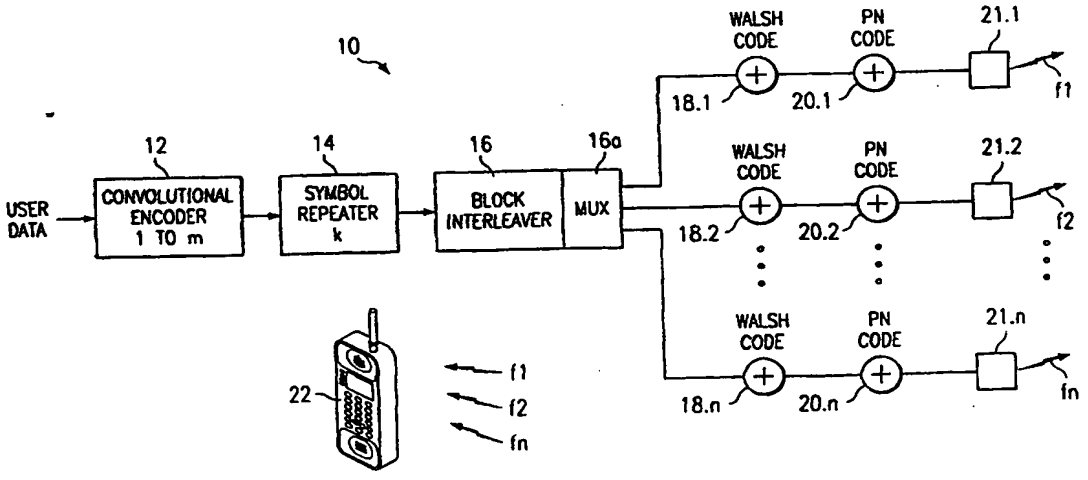

(57) Abstract

A system and method that codes and interleaves data onto separate channels for transmission in a wireless multicarrier system, further comprising a code division multiple access (CDMA) transmitter for each of the carriers. The multicarrier wireless transmission system has an input terminal for receiving a plurality of user data bits. The system adds error–correcting bits to the user data bits. The system then arranges and stores the combination of error–correcting bits, collectively coded symbols, in a two dimensional matrix. The system arranges the coded symbols by writing them into the matrix according to columns, from left to right. The system then retrieves the symbols from the matrix according to rows, from top to bottom. The system then transmits the retrieved symbols on different carrier frequencies such that consecutive symbols are each transmitted on a different carrier frequency.

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AMENDED CLAIMS

[received by the International Bureau on 13 January 1999 (13.01.99); original claim 9 cancelled; original claims 1, 3-6, 8, 10, 12 and 13 amended; claims 10-20 renumbered as claims 9-19; remaining claims unchanged (4 pages)]

1. A telecommunication system comprising:

an input terminal for receiving a plurality of user data bits;

an error-correction device for generating a sequence of coded symbols from the user data bits;

an interleaver for arranging and storing the coded symbols in a matrix; and

an inverse-multiplexer for serially retrieving the coded symbols stored in the matrix and distributing the retrieved coded symbols across a plurality of carriers;

wherein the matrix is two-dimensional, the interleaver arranges the coded symbols according to the first dimension and the inverse-multiplexer retrieves the coded symbols according to the second dimension.

2. The system of claim 1 further comprising a device for repeating the coded symbols.

3. The system of claim 1 wherein the error correction device comprises a repeater and the sequence of coded symbols include duplicates of the user data bits.

4. The system of claim 1 being a wireless multicarrier system further comprising a code division multiple access ("CDMA") transmitter for each of the plurality of carriers.

5. The system of claim 4 wherein a sub-sequence of multiple coded symbols is generated for each user data bit and wherein consecutive symbols of the sub-sequence are transmitted on different ones of the plurality of carriers.

6. The system of claim 2 wherein the repeated coded symbols are sequentially transmitted on different ones of the plurality of carriers.

7. The system of claim 1 wherein the error-correction device provides forward error correction.

8. The system of claim 1 wherein each of the plurality of carriers operates at a common bandwidth.

9. The system of claim 1 wherein the system may selectively use one or more of the plurality of carriers.

10. A method for arranging a frame of consecutive bits for transmission in a multicarrier system, the method comprising the steps of:

arranging and storing each bit of the frame in a two-dimensional matrix according to the first dimension of the matrix;

retrieving each bit stored in the matrix according to the second dimension to form an interleaved sequence of bits;

transmitting the interleaved sequence of bits with multiple carriers such that no two consecutive bits in the interleaved sequence of bits are transmitted on the same carrier.

11. The method of claim 10 wherein the step of transmitting utilizes multiple carriers and no two consecutive bits of the frame are transmitted on the same carrier.

12. The method of claim 10 wherein the first dimension represents a plurality of arrangements of the matrix, and where a first carrier transmits the first bit of a first arrangement and a second carrier transmits the first bit of a second arrangement.

13. The method of claim 10 wherein the step of transmitting utilizes a code division multiple access ("CDMA") transmitter for each carrier of the multicarrier system.

14. The method of claim 10 wherein the frame of bits includes error-correcting code.

15. The method of claim 14 wherein the frame of bits also includes user data and the error-correcting code is a duplicate of the user data.

16. The method of claim 10 wherein each carrier of the multicarrier system operates at a common bandwidth.

17. The method of claim 10 wherein the multicarrier system utilizes only a single carrier.

18. A system for arranging a frame of consecutive bits for transmission in a multicarrier wireless system, the system comprising:

means for arranging and storing each bit of the frame in a two-dimensional matrix according to the first dimension of the matrix;

means for retrieving each bit stored in the matrix according to the second dimension to form an interleaved sequence of bits;

a code division multiple access transmitter for transmitting the interleaved sequence of bits wherein the step of transmission utilizes multiple carriers operating at a common bandwidth and wherein no two consecutive bits of the frame are transmitted on the same carrier;

wherein the first dimension represents a plurality arrangements of the matrix, and where a first carrier transmits the first bit of the first arrangement and the second carrier transmits the first bit of the second arrangement.

19. The system of claim 18 wherein the frame of bits includes error-correcting code.